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Advanced Transportation Location & Information Service • ATLIS • Berkeley CA

Ex parte presentations

March 17, 2008

Marlene Dortch
FCC, Office of Secretary
445 12th Street, SW
Washington, DC 20054

FILED/ACCEPTED
MAY - 4 2008
Federal Communications Commission
Office of the Secretary

Re: WT 06-49: the *LMS-M ITS Radio Service* NPRM.

Attached hereto is a copy of a paper:

in *GPS World, Military & Government*, March 1, 2007

"Tests of a Flexible Pseudolite Based Navigation System"

with **Notes on Implementation by Telesaurus and Skybridge for LMS-M**

This is a written presentation, by filing in the docket on ECFS, to further supplement the record on a critical question underlying (and that caused) the NPRM: will equipment for LMS-M become available and will LMS-M succeed. If the answer is **yes—*and it clearly is***—then the rules should not be changed, as reflected in the rationale used to establish RM-10403 and then the NPRM.

In our filing of 3.7.2008, we identified and discussed the advanced digital land mobile radio technology, *TETRA*, that is especially suitable for the vehicle-to-ITS system *communication* component of LMS-M systems.

Now, in the instant filing, we identify and discuss (in addition to our past filings on this subject) the *essential technology for multilateration component of LMS-M systems, **pseudolites***.

Further, margin notes in the attached explain additional ***pseudolite***-related location techniques (also published) that we plan to use to enhance the basic techniques explained in this article and used in the tests it reports, *to achieve sub-meter accuracy for moving vehicles throughout a market, even in urban cores.*

LMS-M spectrum is allocated as the only wide-area ITS radio service principally for vehicle location using multilateration techniques, ***for which the current power levels and time of use (and other current rule parameters) are essential***. Certain associated voice and data communication is allowed. ***Pseudolite*** technology is the best means to implement such multilateration, and is planned by Telesaurus Holdings GB LLC and Spectrum Skybridge Foundation, as previously discussed many times in written and oral presentations in this docket.

The attached article supplements the record with regard to ***pseudolite*** technology, a relatively new field, especially with regard to substantial wide-area implementation. While this discusses only some forms of ***pseudolite*** technology and implementations, it is effective to demonstrate core principals and benefits. The article is by well-known authorities in the field, some of whom are based in the US. Tests discussed were carried out near Washington DC.

Thus, contrary to the central premise of Progeny that is the basis of the NPRM—that technology and equipment for LMS-M multilateration is not feasible, and therefore other uses of LMS-M must be allowed—*far better technology and equipment is now becoming available* than originally contemplated by the Commission in the mid 1995 for LMS-M multilateration (pseudolites and related) and associated communications (TETRA Releases 1 and 2), *and far more full and important ITS applications* will be served by it than even the bold set of essential ITS applications described by the Commission in the Orders establishing the LMS-M ITS Radio Service.[1]

Respectfully,

/s/
Warren Havens
President,
ATLIS Wireless LLC,[2]
Telesaurus Holdings GB LLC
Skybridge Spectrum Foundation
and their affiliates listed above

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[1] See, e.g, the numerous filings in this docket by Telesaurus-Skybridge, and in support thereof, ITS America, ITS California, University of California-CCIT, and Professor Raja Sengupta. See also www.telesaurus.com, including page on ITS Solutions, and www.tetra-us.us (some pages discuss ITS use of TETRA).

[2] ATLIS Wireless LLC was formed in 2007 to provide operational services to the other entities listed above including Telesaurus Holdings GB LLC that holds LMS licenses nearly nationwide, and also assists Skybridge Spectrum Foundation that also holds LMS licensees nearly nationwide.

Attachment

Figures herein, in expanded format, are attached at the end.

GPS World MILITARY & GOVERNMENT

Survey & Construction | Military & Government | Avionics & Transportation | LBS | Mass Market OEM | Utilities & Communications | System Design & Test

This is filed in FCC 06-49 docket as an overview of some of the fundamental principals and techniques in terrestrial pseudolites to augment GPS, including pseudolites using non-GPS spectrum. (GPS or non-GPS signalling can be used for these.)

Piercing the Veil

Tests of a Flexible Pseudolite-Based Navigation System

Mar 1, 2007

By: Aleksandar Jovancevic, Nikhil Bhatia, Joseph Noronha, Brijesh Sirpatil, Michael Kirchner, Deepak Saxena

GPS World

Destruction or degradation of the GPS constellation or its integrity would be catastrophic, and means must be provided for the ever-increasing sets of equipments and ammunition systems that depend on GPS for their functionality. Pseudolites produce GPS-like signals and have been under consideration for various situations. A major difficulty with pseudolites is the near-far problem, where the coverage range is generally limited due to the dynamic range limitations of commercial GPS receivers. We have considered several other issues in designing our software-radio based pseudolite, including the coexistence of the pseudolite (PL) signal alongside GPS with use of a pulse-blanked participative receiver.

As early as 1986, experts proved that pseudolites could serve as an effective augmentation to the existing GPS constellation and proposed a pulsed-signal scheme as the best way to provide PL ranging signals without adversely affecting other GPS receivers in the area. Further research indicated that pulse blanking would effectively combat pulsed interference at the receiver. Such earlier work enabled us to develop a flexible software-based PL system incorporating a pulse-blanking scheme with the ability to switch on/off the pulsing feature, to aid in mitigating the near-far problem. The receiver would also be able to use both GPS and PL signals simultaneously to enhance navigational accuracy.

The PL assembly receives positioning information either through GPS or any other external reference sources and generates a waveform containing positioning information. The GPS+PL receiver uses the pseudolite and/or GPS signals to provide accurate navigation.

Near-Far Margin

One of the main problems associated with launching new PLs is the emergence of near-far effects, where the strong signal near the GPS receiver dominates reception of the weak signal from distant transmitters. PLs launched in the theatre of operation will suffer from this dynamic range problem.

FIGURE 1 illustrates the near-far effect: the PL signal can get as strong as 60 dB as the receiver moves towards the PL from a distance of 50 kilometers to 50 meters. Assuming the PL transmits the signals on CA code, the cross-correlation peaks between the satellite and PL CA codes is 21.6 dB worst-case. The (60 – 21.6) = 38 dB-higher PL signal

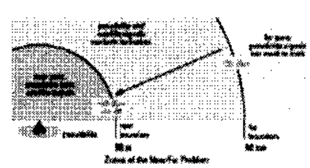


Figure 1 Near-far problem

Figures herein, in expanded format, are attached at the end.

Notes by Telesaurus & Skybridge:

This 2007 article presents some of the central principals of psuedo-lites used with GPS.

Use of pseudolites+GPS for wide-area systems in its infancy, but it is clear that technology exists for such systems, and (not much indicated below) some commercial systems have commenced (Telesaurus-Skybridge have discussed this in other documents).

There are a number of associated parties or groups involved in developmenrt of pseudolite technology and applications. The parties presenting this article do not present matters involved with some some other groups.

For nationwide ITS wide-area wireless, Telesaurus-Skybridge is developing systems that use of some techninquies noted herein, some from other such groups, and also use of RTK, Intertial Navigtion Sytems on board vehicles, and additional location techniques with LMS-N.

The LMS-M spectrum, at CURRENT POWER and TIME of USE LEVELS is REQUIRED for these implementations.

therefore dominates the receiver at 50 meters.

We set out to find the near and far distances where a receiver can track both PL and satellite signals. The GPS receiver requires a minimum of 6 dB signal-to-noise ratio (SNR) for tracking the GPS signals. With the cross-correlation peaks of 21.6 dB between the CA codes, the SNR margin available at the receiver is 21.6 – 6 = 15.6 dB. A 15.6 dB corresponds to a near-far ratio of 6:1. One can therefore place a PL at a point and operate the GPS receivers between distance *d* and *6d* without any problems. The difficulty with this approach, however, is that all the signals at receivers within distance *d* from PL will be blocked. The 6:1 ratio may be overly optimistic; the practical ratios used are close to 3:1.

Solutions to the near-far problem include:
Different Frequencies. The problem can be removed by sending the PL signals at frequencies different from the GPS frequencies: signals transmitted at a frequency offset from L1 (1575-42 MHz), but within the same frequency band as GPS, a variation of frequency division multiple access (FDMA). This robust approach, however, requires the modification of the existing receiver hardware.

High Rate, Longer Lengths. Alternative codes can have a longer sequence than the existing GPS code, a variation of code division multiple access (CDMA). The autocorrelation and cross-correlation properties of the codes can be improved by using longer, high-rate codes. This again would require a change in the existing correlators.

Pulse Technique: pulsed signals with random or fixed cycle rates, a time division multiple access (TDMA) variation. The RTCM-104 committee proposed that the PL signals be transmitted in frequent, short, strong pulses. Despite the low pulse duty cycles (PDCs), the strong pulses enable the tracking of the PL signal. The interval between pulses, when the PL transmitter is turned off, allows receivers to track the satellite signals without interference.

Civil aviation applications of pseudolites were considered as early as 1984. The CDMA approach with different pseudorandom noise (PRN) codes could be part of the diversity solution, but longer sequence codes would not add significant margin against cross-correlation interference.

As part of RTCM user activities, a more definitive pseudolite signal structure was proposed in 1986. All three multiple access techniques listed earlier were considered, but pulsed TDMA was the only approach recommended, because it made the least impact on the design of GPS receivers based on the state of technology at the time.

Subsequently, flaws in the TDMA scheme were observed with respect to a class of nonparticipating receivers, some of which are still in use today. This led to a modified TDMA scheme in 1990. Despite these proposals, fear of the near-far problem remained, because a limited interference margin can still exist with only code (CDMA) and pulsing (TDMA) employed.

GPS receiver technology has advanced to a point that the FDMA approach is now practical, which improves the solution to the near-far interference issue significantly. As a result, a more effective signal structure has been proposed that combines good C/A codes, a frequent offset that takes advantage of the code cross-correlation properties, and a good pulsing scheme.

The Wide-Area Augmentation System uses some of the possible C/A codes. Several other codes, good in terms of cross-correlation properties, are available and can be used for pseudolites. A frequency offset of 1.023 MHz on either side of L1 at 1575.42 MHz places the PL carrier in the first null of the GPS satellite C/A code spectrum. This offset can be accommodated by most current receiver hardware and front ends. The algorithm for carrier and code tracking, however, must consider the offset.

Recently it has been shown that cross-correlation levels can be somewhat higher than indicated earlier when the code-chip boundaries are not aligned. However, when the carrier frequency is offset by 1.023 MHz and the carrier/code frequency ratio of 1540 is maintained, the code of the PL is shifting with respect to the satellite codes at a rate of more than 664 chips per second. Thus, any cross-correlation is noise-like and averages to a lower root mean squared (rms) level. This is still interference. An in-band frequency offset of 1.023 MHz lowers the rms interference by about 8 dB, but does not eliminate it. However, it does eliminate cross-correlation problems.

An entirely different frequency band can be used if one is willing to introduce modifications (add-on) to existing receivers. A front-end modification (frequency division) is necessary. The frequency should be divided by a fixed amount (and not translated, that is, shifted using conventional mixing) in order to accommodate the Doppler shift associated with the PL or the host vehicle. If the Doppler is negligible, simple frequency translation can be used. This is necessary in order to maintain the relationships between the code and carrier.

Of all these methods, the pulsing scheme is the most promising technique to combat near-far effects. TDMA pulsing, on the other hand, could resolve the near-far problem because most of the receivers will chip-off the interference signals or pulses, and one does not have the extreme dynamic range requirements. With a good pulsing scheme, impact on GPS signal reception can be made essentially transparent. The receiver treats it as a continuous signal, provided that it is designed to suppress pulse interference, as most modern receivers are, even if by accident.

All modern digital receivers are either hard-limiting or possess the soft-limiting property through pre-correlation quantization. Although this is not true for the older, analog military receivers, their wideband automatic gain control (AGC) suppresses the pulses for the same effect. Any cross-correlation problems in those receivers caused by PL transmissions are eliminated with the proposed frequency offset.

Timing of the pulsing scheme must be asynchronous to the GPS bit pattern. The pulsing scheme will allow tracking of both C/A code and the carrier, even when the pulse duty cycle is less than 10 percent. One or more pulses will always be integrated over each symbol, and the result will be transparent to the existing receiver tracking loops.

While possible solutions offer different complexities — ease of use, accuracies, and so on — their choice depends on the theater of operation, siting of auxiliary GPS PL-like devices, line of sight, timing synchronization, and so on. Resulting accuracies are determined by PDOP and VDOP, the signal to noise, signal to jamming ratio, and also on the receiver front end, receiver dynamic range, filters, nonlinearities, and, most importantly, on the carrier and code tracking loops and navigation filters. Based on our research, we propose the pulsing technique to combat the near-far effects.

Pulsing Technique

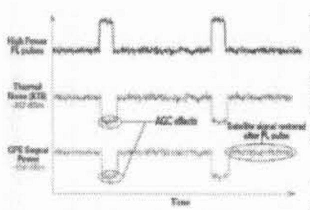
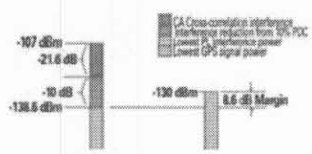


Figure 2 Pseudolite/GPS interaction

FIGURE 2 illustrates the effects that the PL pulse has on the satellite signals. As the short, high-power PL pulses arrive, the AGC mechanism kicks in, and the power levels for the GPS signals are attenuated. The satellite signals are restored to the original level when the PL pulses end.

The GPS receivers can be classified in two types of receivers. The existing, non-participating receivers will still be able to track the GPS signals with minimal interference in the presence of PLs, as they are unable to track or decode the PL signals. Participating receivers with some software modifications can receive and decode both satellite and PL signals.

FIGURE 3 shows the effects of PL on the GPS signal reception in a non-participating receiver. The PL signal is saturated at –107 dBm by the AGC circuitry. The total interference power from the PL signal can therefore be



Figures herein, in expanded format, are attached at the end.

calculated as –107 dBm – 21.6 dB (cross correlation between the CA codes) – 10 dB (assuming the PL to have a PDC of 10 percent) = – 138.6 dBm. Since the minimum GPS satellite signal reaching the receiver is specified as –130 dBm, the SNR margin obtained is –130 + 138.6 = 8.6 dB.

With a tracking-loop SNR requirement of 6 dB, the available margin reduces to 8.6 – 6 = 2.6 dB. Furthermore, for a PL pulse with PDC of 10 percent, the GPS satellite signal is lost for 10 percent of the total time resulting in a loss of 10 x log(0.9) = 0.5 dB. This further reduces the available margin to 2.1 dB, still greater than 0, implying that the GPS satellite signals can still be tracked in the presence of PLs.

For participating receivers, performance improvement can be obtained by blanking out the PL pulses while tracking the GPS satellites and vice versa. Thus, the PL correlators must be disabled when the GPS signals are tracked, and GPS correlators must be disabled when the PL signal is tracked. One of the major issues with PL signal reception is the transfer of the PL ephemeris information. The navigation message must be modified to provide the receiver with the ephemeris information depending on whether the PL is a stationary ground-based PL or an airborne PL.

Implementation

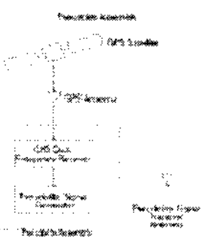


Figure 4 Pseudolite transmitter framework using GPS as the external reference source

The pseudolite transmitter determines its position and timing information through an external source (for example, GPS signal). It then generates a navigation message and transmits the same via the pseudolite RF front end. The frequency of transmission of the PL will either be the same as that of GPS or at an offset frequency. **FIGURE 4** gives an overview of this assembly.

The GPS signals behave as external reference sources to provide the position and timing information to the pseudolite. This information is the basis of the pseudolite ephemeris. The receiver incorporated in the pseudolite has pulse-blanking ability to be able to receive the GPS signals and transmit the pseudolite signal simultaneously. This is required to prevent the stronger pseudolite signal from overpowering the GPS signal at the input of the pseudolite. The pseudolite signal generator takes in the timing information (along with clock bias/clock drift) and position information computed using the external reference and generates a navigation message. The signal is then pulsed at the rate of 2 milliseconds (ms) every 19 ms and transmitted through the pseudolite RF front-end.

Figures herein, in expanded format, are attached at the end.

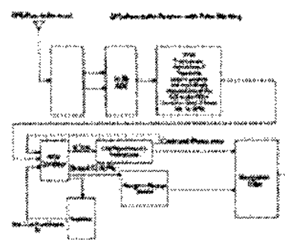
The pseudolite will be equipped with a laptop that will behave as the controller for the whole system. The controlling inputs which are provided are

- initialize date, time and location
- indicate type of pseudolite: stationary or otherwise
- position update rate

In the normal operating mode, this reference of time and position will be provided directly through an external GPS receiver. However, if a precise surveyed location and calibration time is known, then this information could be provided to the PL through the controller.

Pseudolite Receiver

A block diagram of a PL receiver appears in **FIGURE 5**. The analog part consists of an antenna and RF front end, responsible for reception, filtering, frequency downconversion, and analog-to-digital (A/D) conversion of incoming satellite signals. One digital signal is produced for the L1 frequency. A number of digital receiver channels (usually not more than 12) each track one of the visible



PL/satellites and collect navigation data transmitted by them. Finally, this data along with timing information is passed to the navigation block, which extracts almanac and ephemeris information from navigation data and performs a position calculation based on pseudorange measurements from the satellites/pseudolite combination.

The signal from the RF front end is sampled and processed using a field-programmable gate array (FPGA) correlator. The correlator output is fed to a general purpose processor (GPP) and processed using software. The software implements acquisition, tracking, and navigation functions and provides all intermediate signal outputs. The downconverter, A/D, and FPGA are all driven by the common reference oscillator. The FPGA also serves as the receiver's internal clock. The GPP software is slaved to the FPGA and periodically receives the correlator outputs and additional data. Every data transfer between FPGA and GPP and back must be time-stamped. This maintains real-time operation even with timing uncertainty due to the communication between FPGA and GPP. Initialization of GPS/PL signal generators is especially critical and must be implemented with great care.

Downconversion. The downconverter accepts L1 PL and/or GPS signals and converts them to a lower intermediate frequency (IF) suitable for digitization by a high speed A/D converter. This design uses a dual-conversion, superheterodyne topology. The first and second IFs are approximately 140 MHz and 14 MHz, respectively. The downconverter IF bandwidth is 16 MHz. The noise figure is 1.69 dB. The overall gain is 70 dB, which produces an output noise signal level of – 32 dBm, assuming an input noise of –102 dBm (16 MHz bandwidth). The output third-order intercept point (OIP3) is +19.1 dBm, which gives an input IP3 of –50.9 dBm.

The A/D converter is a 12-bit device, sampling at 60 MSPS. The downconverter gain is set so that the two least significant bits of the A/D converter toggle on the amplified noise. This leaves several bits of headroom at the A/D converter for anti-jam performance. The number of effective bits can be configured by the user (12 maximum).

The local oscillators for the first and second mixers are generated with dual-modulus synthesizers, locked to a common, high-stability frequency reference. The frequency plan was chosen so that these synthesizers operate in single-modulus mode. Programming information for the synthesizers is stored in the onboard programmable read-only memory (PROM). Should operation at other frequencies be desired, the PROM can be easily reprogrammed for the new frequencies.

The FPGA preprocessor at the output of the A/D determines if the PL pulse is present and accordingly allocates bits of the ADC to the FPGA correlator core (lower three bits if GPS).

Software. The software correlator using C++ is translated into very high-level design language (VHDL) for driving the FPGA correlator, which accepts signed data from the A/D converter and processes the data for early, prompt, and late code phase tracking. The results are accumulated and output is sent to the software portion of the receiver, at a reduced data rate. The correlator also performs the time measurement for pseudorange calculations. Both C/A and P-codes are generated in the correlator pre-processor. It also performs carrier mixing and I/Q accumulation. It can also be programmed for beam-forming, beam-steering, and other pre-processing activities for interference rejection, multipath measurements and mitigation, and so on. Similar performance can also be achieved using DSP pre-processors.

Digital processing is responsible for acquiring and tracking the pseudolites and/or GPS satellites. First, the algorithm performs a search for PL/satellites in view, or, if valid almanac information and approximate receiver position and time are available, estimates which PL/satellites are visible and attempts to acquire them. After acquisition, the code phase and Doppler of each acquired satellite are used to initialize the tracking loops. These loops (carrier and code loops) are updated continuously so that satellite and receiver dynamics can be tracked. Also, the receiver must be synchronized with the 50-bps bit-stream that is transmitted from each satellite to obtain navigation data defining the satellite orbits, PL position, and associated dynamics along with other relevant parameters, and also to be able to correctly determine PL/satellite pseudoranges and pseudorange rates (timing information), which are collected and passed to the navigation block.

Nav Block. The navigation block calculates position when sufficient combinations of PL/satellites are tracked. It updates the receiver state vector using Kalman filtering. It can also aid acquisition by estimating Doppler shift and satellite positions when a new PL/satellite is being acquired or during reacquisition.

The receiver has the ability to receive both/either GPS and PL signals. The output interface of the receiver is the position and time, similar to that in a GPS receiver. A terrain map will also be provided indicating the location of the receiver and available constellation of satellites/pseudolites being used for navigation. The receiver is a participative receiver in that it can simultaneously receive both GPS as well as pseudolite signals and process them accordingly.

The receiver can be configured via software to receive GPS+PL or PL only signals.

PL Software Receiver

A block diagram of the PL receiver using the software framework has been shown in Figure 5. The receiver can easily be modified to include PL C/A code, PL C/A + PL1 code or PL C/A+PL1+PL2 codes. The current configuration is designed to be a four-channel single-frequency C/A+PL1 code receiver. The receiver can be extended to 12 or more channels and accommodate varying combinations of PL and GPS.

The software PL/GPS receiver is implemented using the development software built at the Center for Remote Sensing. The software is written in C++ and provides a tool to design, simulate, test, and implement various systems using building blocks. Each block has inputs and outputs with precisely defined transfer functions between them. The output from the block can be triggered either by a clock signal or by one of the inputs. Each of the inputs or the outputs has a defined type, which prevents connecting inputs and outputs that are not compatible. Types range from numerical types such as integers and floating point numbers through complex values to PL specific data structures such as subframe data and timing information.

I/O. Inputs and outputs are connected through channels, which can be attached to a plotting module to graphically represent channel data. We implemented various plotting modules, such as time plot, sliding plot, I-Q plot, and so on. A probe module shows channel data numerically. PL/GPS-specific data structure types have decoder modules built to facilitate representation of these types of data. Each module can have additional parameters that can be modified before or during the simulation. A snapshot of the simulation can be taken at any time with all necessary parameters saved. This is particularly useful for comparison of different receiver designs when the simulation must be performed with the same initial conditions.

The PL receiver has a comprehensive graphical user interface (GUI) showing various parameters of the pseudolites/satellites being tracked. It includes position, velocity, and acceleration of the pseudolites, receiver position and velocity, pseudorange, and other parameters including the tracking state of the pseudolite/satellites (subframe synch, tracking, and so on).

Status messages including the health of the PL (OK/Bad/No data) are also provided. All the data provided on the GUI can also be logged for post-processing analysis.

PL Operating Modes

The pseudolite is designed to operate in the following modes:

- GPS enabled: Here GPS would serve as the external position and timing information source.
- external (non-GPS) enabled: An external source would provide position and timing

information.

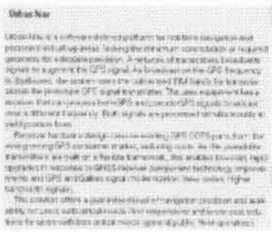
- insertion of new navigation waveform (pseudolite ephemeris)
- variable update rate

Has value when using LMS-M for PLs.

The CRS pseudolite family comprises:

- pseudolites transmitting in the GPS band (L1)(PL-L1)
- pseudolites transmitting in the 915 MHz industrial, scientific, and medical (ISM) band (PL-915)

900 MHz LMS-M needed for wide-area ITS vehicle systems since the power level is needed, among other reasons. And 200 MHz at similar or higher power levels will be used for the more rural areas.



Urban Nav

The 915 MHz ISM is usable by any user under most situations. Both classes comprise GPS-like signal waveforms and both C/A code and P-code capabilities are provided. An UrbanNav version of the pseudolite system employs the ISM band; see **SIDEBAR** for details.

Typically, four pseudolite transmitters with known positions are needed to obtain unambiguous positions and time estimation. It is also necessary to have accurate time synchronization between the pseudolite transmitters.

Pseudolite positions can be obtained from:

- external sources (from ethernet or keyboard)
- built-in GPS receivers

When the GPS signal is not available to the pseudolite transmitter (inside a building, tunnel, and so on), predetermined positions can be used for fixed siting of PL transmitters. PL transmitters also require very accurate time synchronization. This can be provided by external stable clocks (10 MHz) or may be derived from the GPS signal and made available through some network. CRS pseudolites offer operations with GPS or with external clocks.

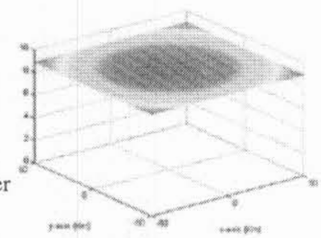


Figure 6 Position dilution of precision (PDOP), four satellites and no pseudolites

Software Simulation Test

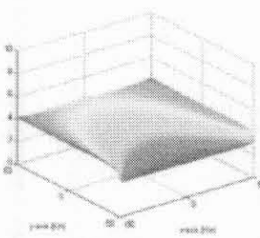


Figure 7 PDOP, two satellites and two pseudolites

Position accuracies are determined by geometrical factors and measurement errors. The measurement errors arise through the pseudorange measurements and are assumed to be zero mean, uncorrelated, and have a common variance. The geometrical factors describe the position accuracies affected by the relative positions between the transmitters (GPS and PLs) and the receivers. The absolute position accuracies are also affected by multipath, ionospheric and tropospheric errors (in GPS), clock errors, and receiver and transmitter biases. The factors are dependent on site, environment, and receiver and transmitter hardware.

Figures herein, in expanded format, are attached at the end.

The geometrical factors represented by position dilution of precision (PDOP) can be easily estimated for different combination of GPS and PL combinations. In **FIGURES 6, 7, 8**, and **9**, the area of coverage was assumed to be 100 x 100 kilometers, and the PLs were positioned at the corners just outside the area of coverage. The PDOP for different receiver positions are computed and shown as gray-scaled contours inside the area of coverage. The shades in the scale indicate the small variation on PDOP within the area of coverage, the darkest being the highest PDOP. The addition of PLs improves the accuracies significantly in almost every situation.

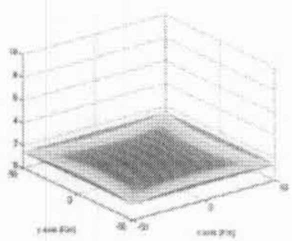


Figure 8 PDOP, four satellites and four pseudolites

Attachment

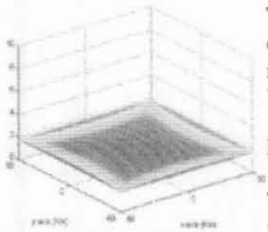


Figure 9 PDOP, one satellite and four pseudolites

The significant decrease in PDOP resulted from the use of PLs in conjunction with various combinations of GPS. The PDOPs were reasonably uniform over the complete region of interest. Variation over the entire region was relatively small.

Hardware-in-Loop Test

Pseudolite test at Bull Run Park, 400 x 400 meter area

The CRS, Inc. signal simulator was used to test the performance of the PL receiver in a laboratory environment. The testing was carried out at the L1 frequency band. This enabled us to test the navigational accuracy in the GPS band without having to broadcast at the GPS frequency. Using a stationary receiver, we considered four different cases for a six-channel (2GPS+4PL) receiver:

- receiver with pulse blanking enabled
- receiver with pulse blanking disabled
- pulse-blanked receiver with external timing resulting in clock drift of 1ns/s
- non-pulse blanked receiver with external timing resulting in clock drift of 1nanosecond/second.

TABLE 1 Position estimates, in meters

	X	Y	Z
GPS	1078502	-4859135	3974920
PL	1078504	-4859132	3974924

Table 1 Position estimates, in meters

FIGURES 10 AND 11 show the results for each of errors in the X and Y axis for a 2D positioning scenario (all PL on ground plane).

In both cases, the errors begin to converge to within an accuracy of 0.1 meters over a period of time. The time for the entire test was 600 seconds. This demonstrates the utility of a pseudolite-based system providing high-precision navigation in the absence of a minimum satellite constellation required for navigation.

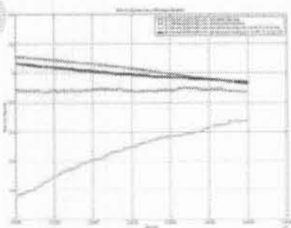


Figure 10 Error in X position

Field Test Results

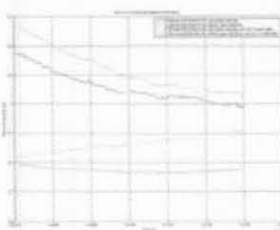


Figure 11 Error in Y position

We carried out a field test at Bull Run Park in Centreville, Virginia, to validate the navigation using the pseudolite system. **TABLE 1** provides the position estimates obtained using a CRS GPS receiver and the pseudolite receiver. It indicates that the pseudolite receiver can provide position estimates comparable to that of a standard GPS receiver. **FIGURES 12, 13,** and **14** show position plots for both the pseudolite transmitters and receivers. The major error source (particularly for ground-based) in the PL system is multipath, and special care must be taken to minimize its effects.

Conclusions

These test results of a pseudolite-based navigation system demonstrate the feasibility of using such a terrestrial system to augment the existing satellite constellation in regions of low satellite visibility or obscuration. The pseudolites can be optimized for different operational situations and can be positioned on either airborne or terrestrial platforms. They find applications in indoor and urban navigation and as augmentation systems for civilian and defense applications.

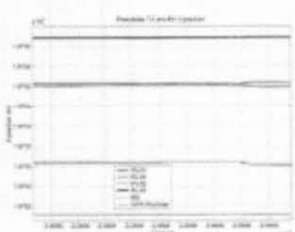


Figure 12 X position [x-axis

Figures herein, in expanded format, are attached at the end.

Telesaurus- Skybridge discloses here, and in other filings in this docket, limited information on its plans since, to defend LMS-M purposes and rules in this NPRM, it is called for. This should not be needed since the NPRM never had sound basis in fact or law.

Higher accuracies (than found in this simple but effective test)--sub-meter-- for moving vehicles, are possible, as Telesaurus- Skybridge plans with combination of:

(i) GPS, PLs (pseudolites), RTK, and INS, and careful placement of PL and RTK transmitters;

(ii) wide-band PL signaling, and Locata-accuracy (nanosecond) PL synchronization;

(iii) the system set up to favor the most accurate PL-RTK covearge areas, and then calibrate INS, and in between, favor INS; and use of LMS-N pass-by location in the areas with worst GPS and PL-RTK coverage.

(iv) Cognitive Radio techniques, dynamic GIS, and smart antenna systems;

(v) correlation with other vehicle's location in nearby higher-accuracy areas and intelligent-system adjustments;

(v) GPS to include other GNSS (Galileo, Glonass, and any others);

(v) other techniques.

Attachment

2s/div, y-axis 50m/div]

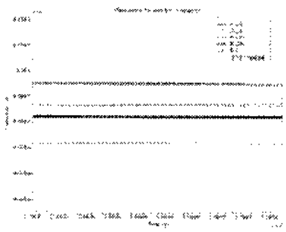


Figure 13 Y position [x-axis 2s/div, y-axis 100m/div]

The pseudolites can operate either in single- or dual-frequency mode and can be configured to allow for pulsing to receive both GPS and PL signals depending on their availability. The software radio architecture permits ease in switching of operating modes depending on the available satellite or pseudolite signal constellation. The pseudolite signal waveform parallels the GPS signal waveform, enabling the same receiver to operate as GPS only, PL only, or as GPS-PL combined receiver at all times. Various efforts to minimize the effects of multipath are currently underway at CRS.

Figures herein, in expanded format, are attached at the end.

This article is adapted from a presentation at the ION GNSS 2006 Conference in Fort Worth, Texas, September 2006. For authors' bios, see the online version of this article at www.gpsworld.com.

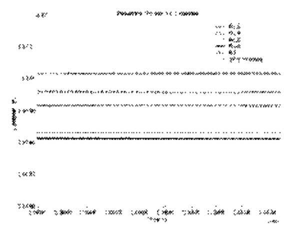


Figure 14 Z position [x-axis 2s/div, y-axis 100m/div]

Manufacturers

The hardware correlator uses a **Xilinx** FPGA.

This test employed SDR-based Pseudolite+GPS equipment, as the article explaine.

Telesaurus-Skybrige plan to use SDR system radios and vehicle radios for both the PL+GPS location functions, and the associated vehicle-to-ITS system communication functions, as has previously been presented to the FCC in this proceeding, with attached SDR board descriptions (from Lyrtech) that operate from 200 to 928 MHz and that support TETRA software waveforms.

An appropriate vehicle-installed SDR can support both LMS-M (and 200 MHz) PL-GPS location and associated LMS-M (and 200 MHz) communications. This is under development.

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Attachment

Piercing the Veil

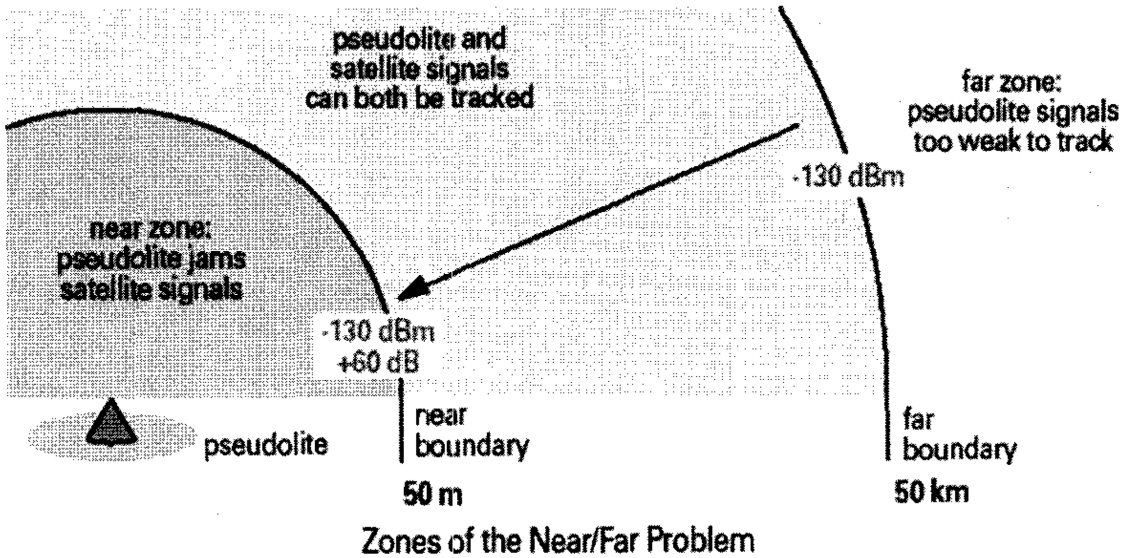

Figure 1 Near-far problem

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Piercing the Veil

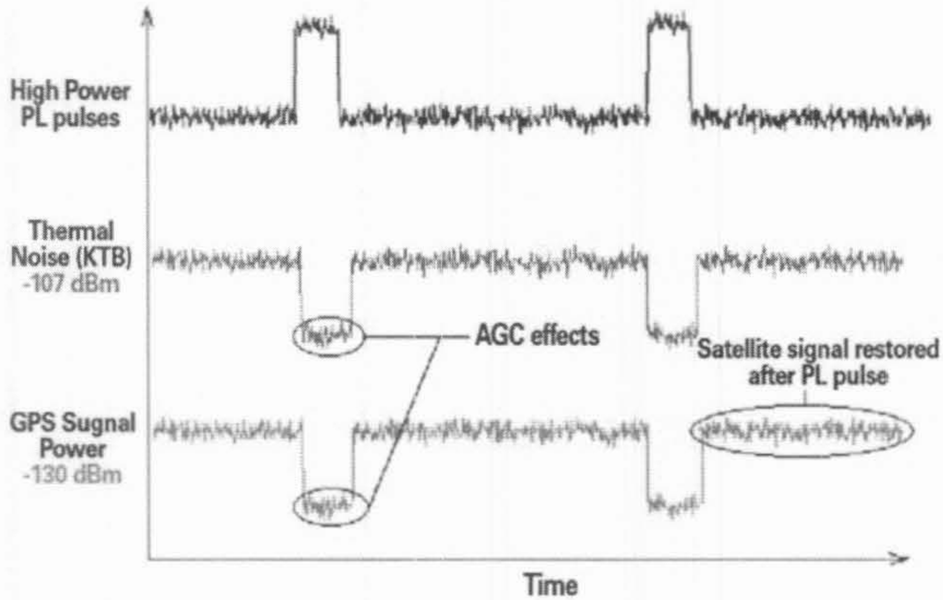

Figure 2 Pseudolite/GPS interaction

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Piercing the Veil

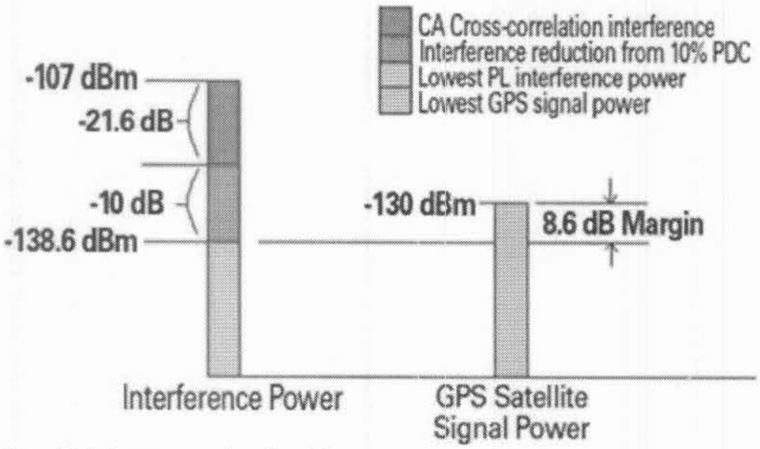

Figure 3 Interference power level from PL

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Piercing the Veil

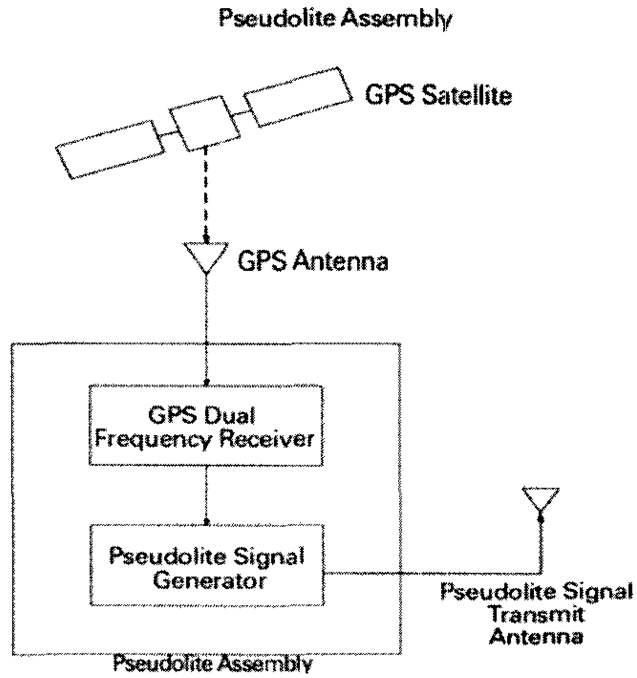

Figure 4 Pseudolite transmitter framework using GPS as the external reference source

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Piercing the Veil

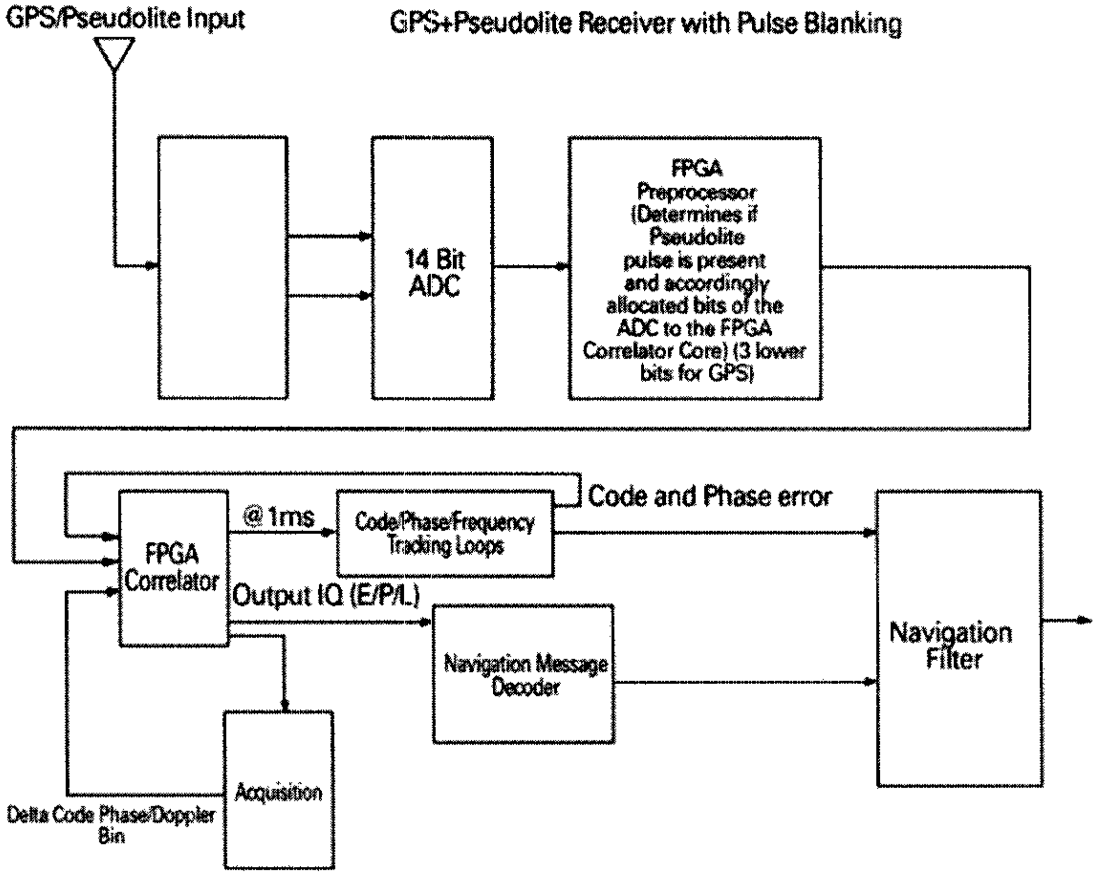

Figure 5 Pseudolilte receiver

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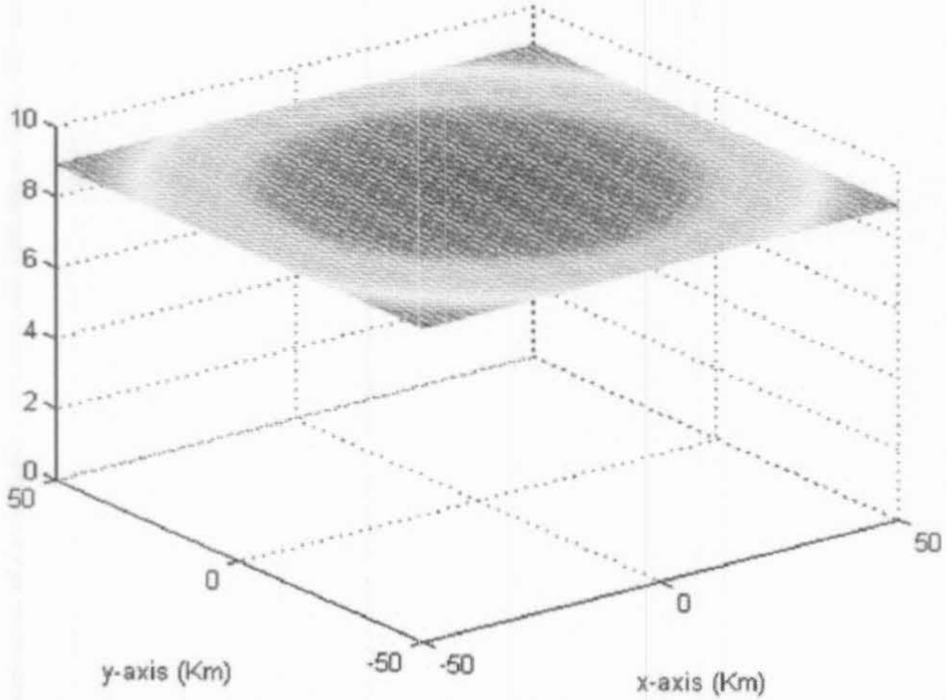

Figure 6 Position dilution of precision (PDOP), four satellites and no pseudolites

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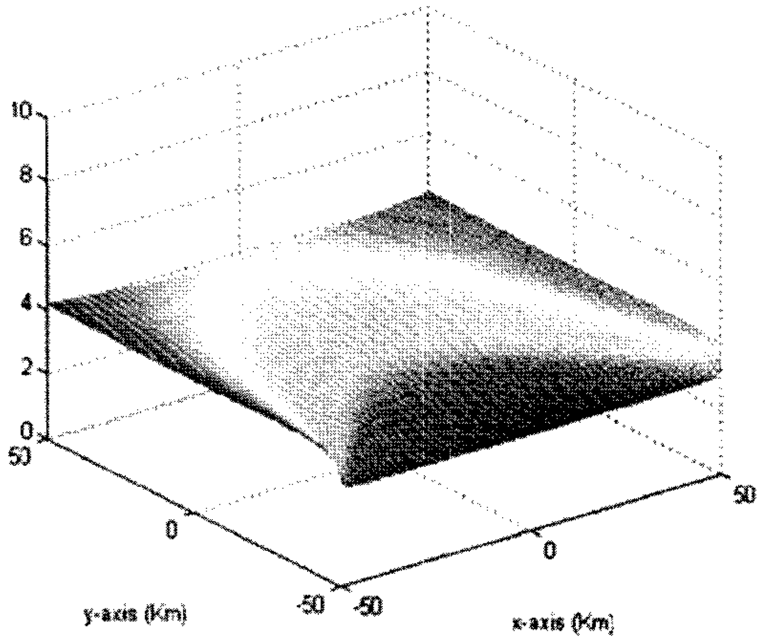

Figure 7 PDOP, two satellites and two pseudolites

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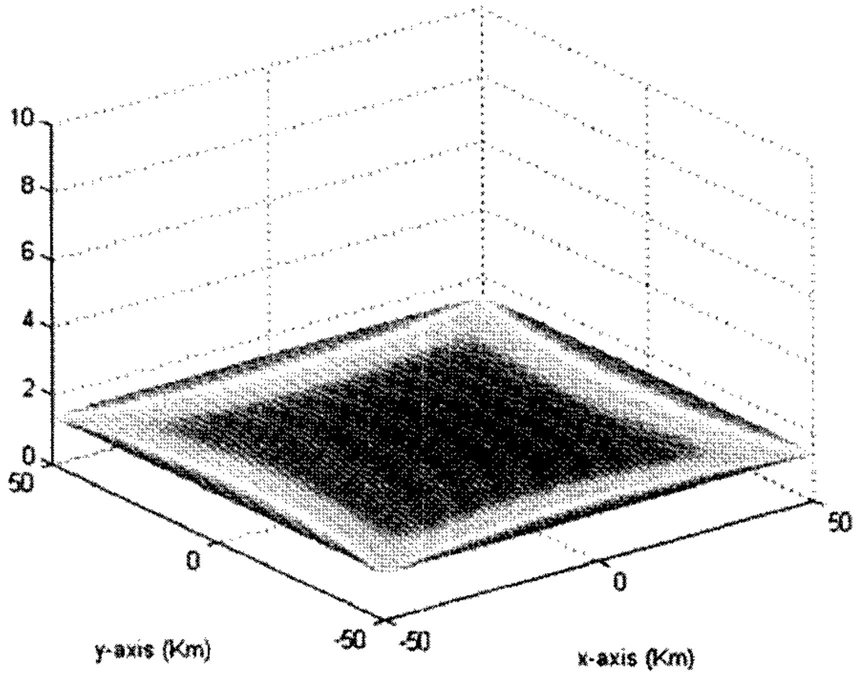

Figure 8 PDOP, four satellites and four pseudolites

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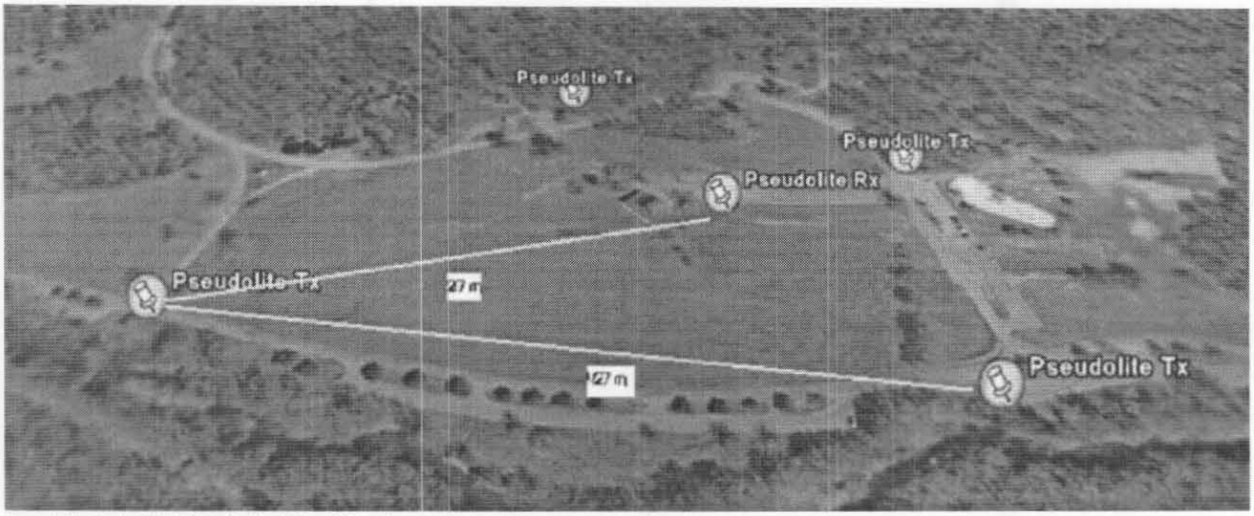

Pseudolite test at Bull Run Park, 400 x 400 meter area

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Attachment

Piercing the Veil

TABLE 1 Position estimates, in meters			
	X	Y	Z
GPS	1078502	-4859135	3974920
PL	1078504	-4859132	3974924

Table 1 Position estimates, in meters

Close Window

Attachment

Piercing the Veil

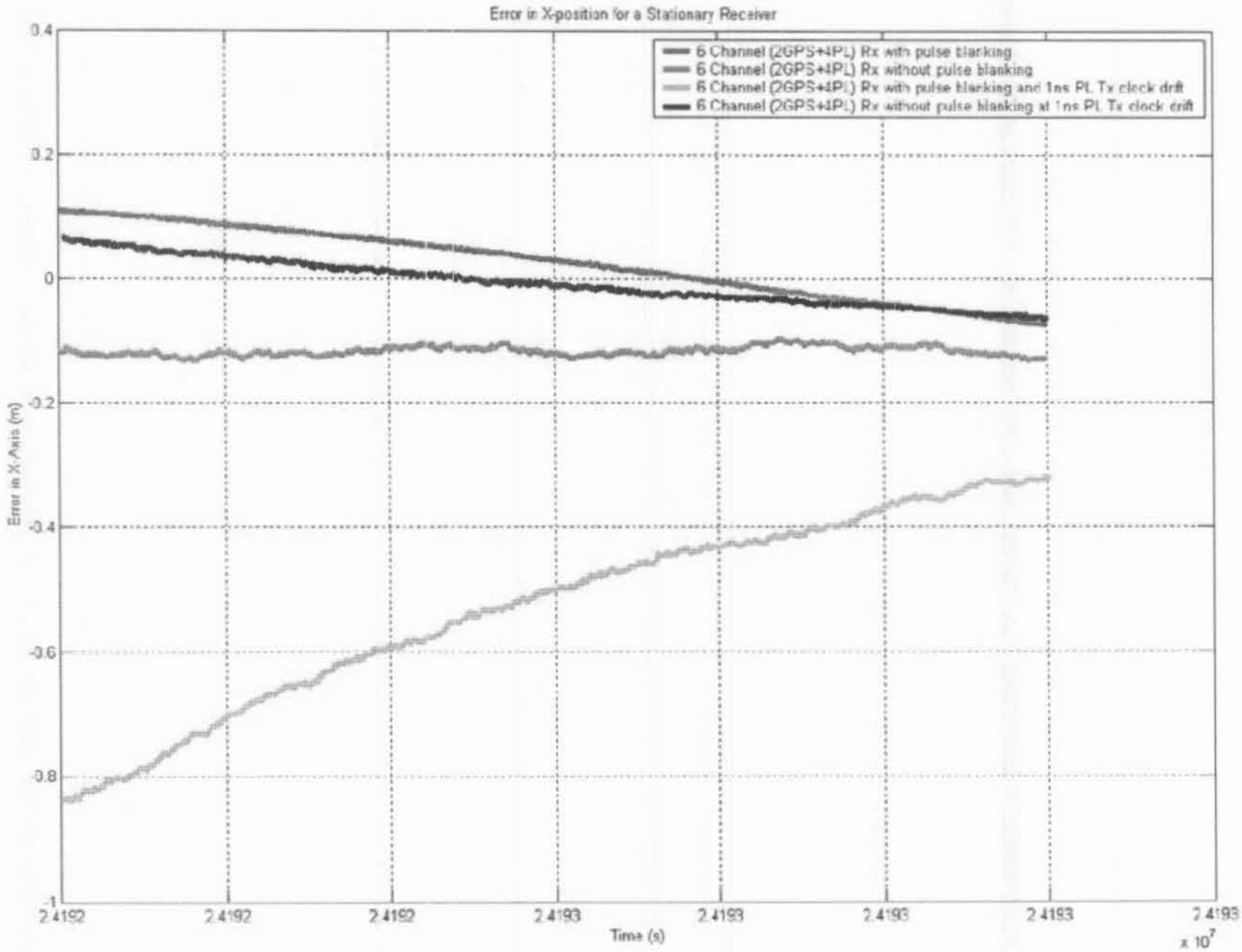

Figure 10 Error in X position

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Piercing the Veil

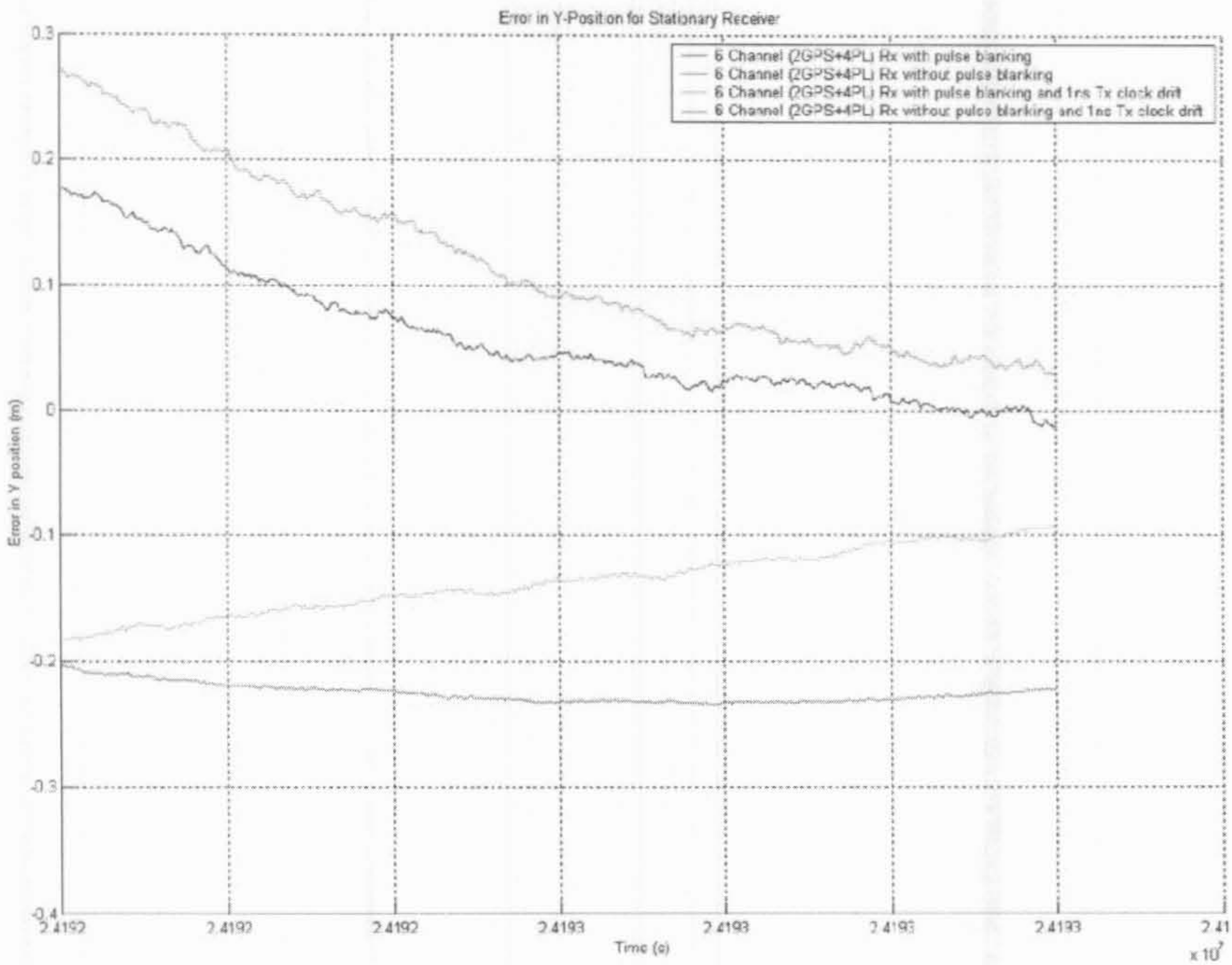

Figure 11 Error in Y position

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Piercing the Veil

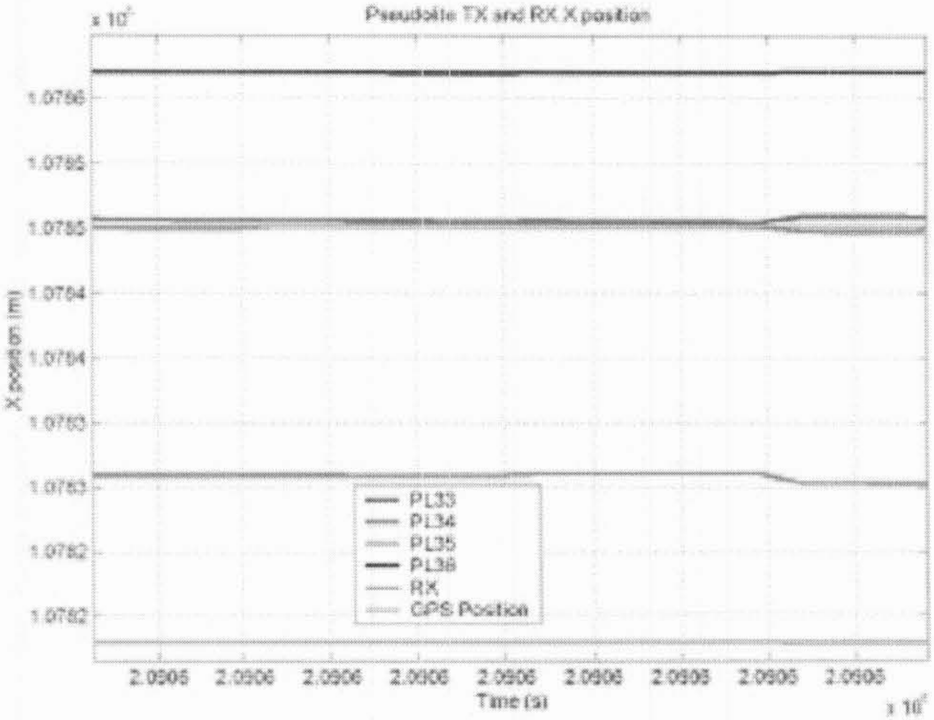

Figure 12 X position [x-axis 2s/div, y-axis 50m/div]

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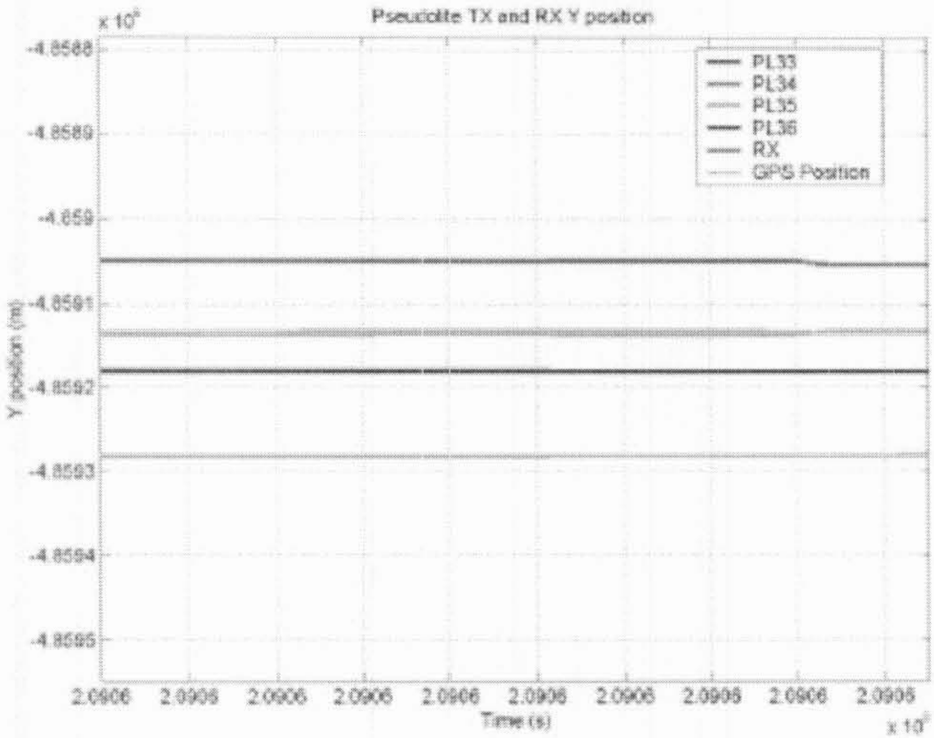

Figure 13 Y position [x-axis 2s/div, y-axis 100m/div]

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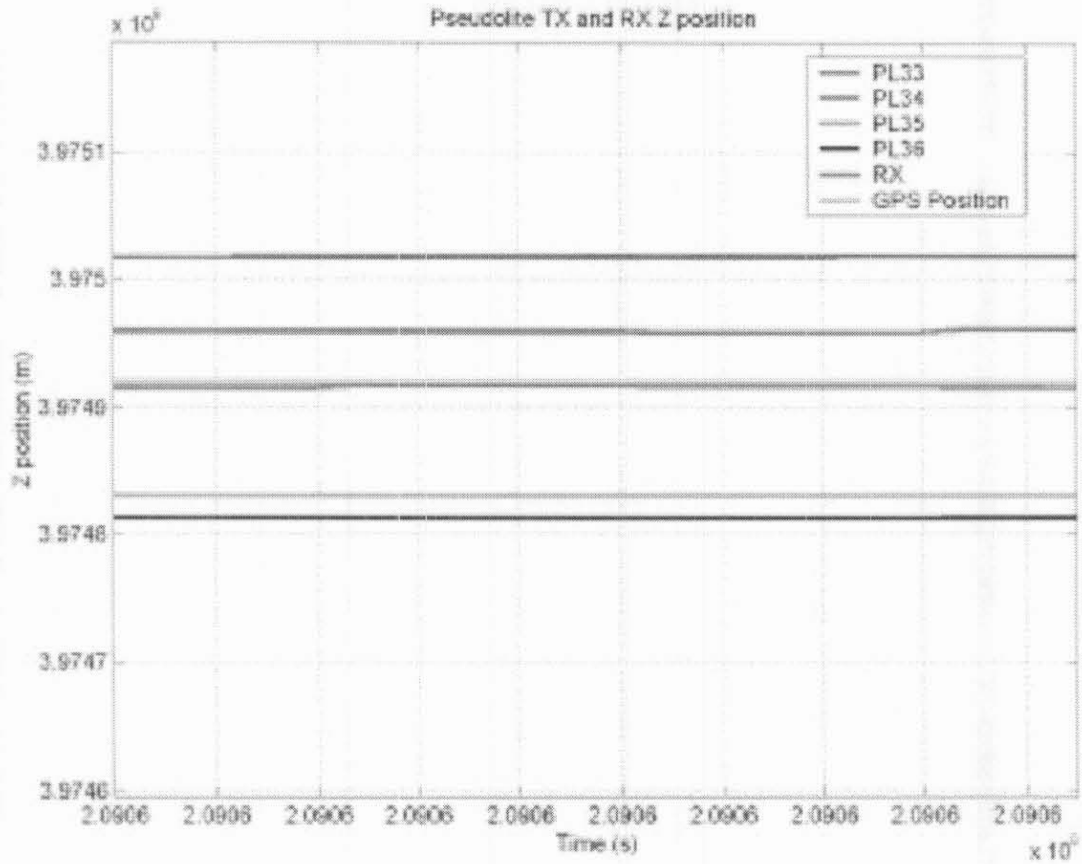

Figure 14 Z position [x-axis 2s/div, y-axis 100m/div]

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